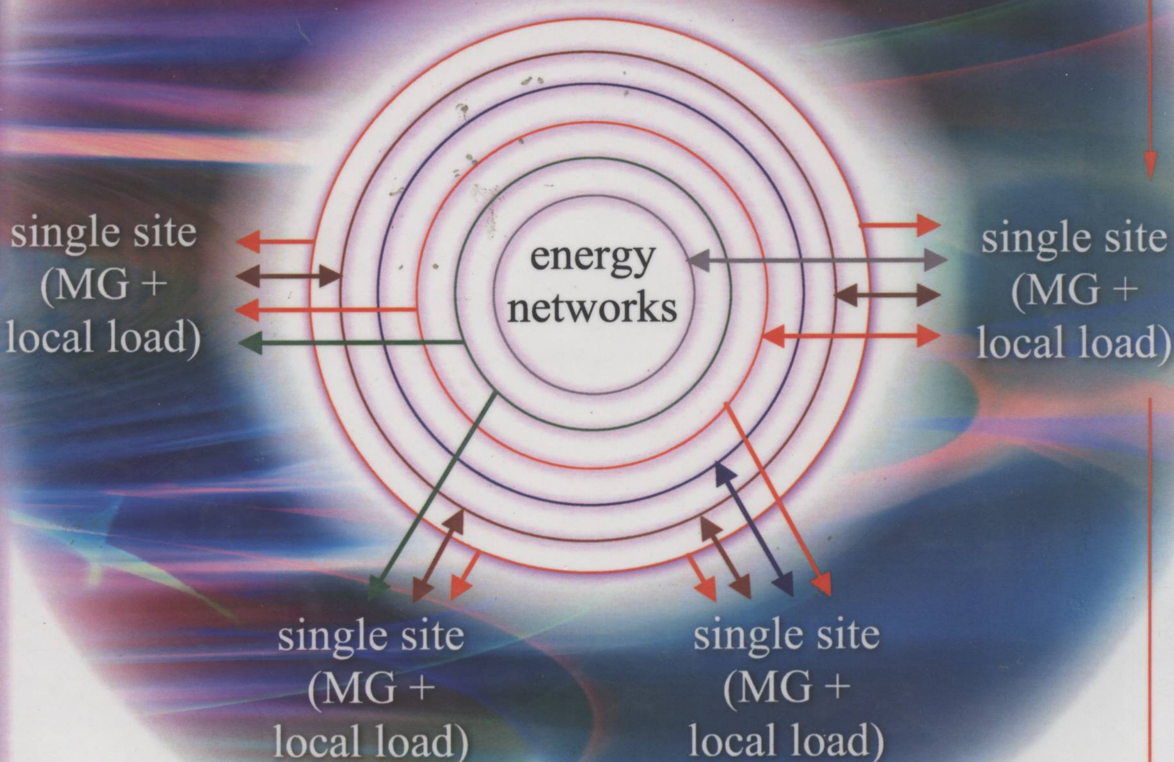
Distributed Multi-Generation Systems

Energy Models and Analyses



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DISTRIBUTED MULTI-GENERATION SYSTEMS: ENERGY MODELS AND ANALYSES

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DISTRIBUTED MULTI-GENERATION SYSTEMS: ENERGY MODELS AND ANALYSES

To Our Families

PREFACE

This book contains a compendium of various research activities carried out by the authors in the latest years in the field of energy efficiency and territorial sustainability of distributed energy production. These activities have been developed by following the specific conceptual line of characterizing distributed systems for combined energy production in a synthetic fashion and by exploiting simple and intuitive energy-based approaches. In this outlook, the energy system components are described through output-to-input black-box efficiency models. The whole energy system model is built on the basis of the component black-boxes and of suitable characterization of the energy flow interactions within the plant and with external energy networks. We identify the interconnected structures analysed with the label "*Distributed Multi-Generation*" and denote it with the acronym DMG.

The content of this book is relevant to a number of aspects related to *energy efficiency*, with further potential extensions to environmental as well as economic analyses. The main objectives are to provide a general overview on DMG structures, with specific focus on Combined Heat and Power (CHP) and Combined Cooling Heat and Power (CCHP) plants, although other energy carriers can be entailed in the framework developed. The reader is assumed to be familiar with basic thermodynamic concepts taught in undergraduate courses of science and engineering. Some of the key issues addressed are DMG plant structures and equipment, component characteristics and models, assessment framework to compare DMG structures with conventional separate production, and examples of energy assessment of various technologies for planning studies. Various openings to other key issues concerning environmental impact, interactions with renewable sources and external networks, and distributed multi-generation economics, are also included. A relevant outcome of the approach presented is that the structure of the indicators derived is consistent with the representation of the primary energy saving indicators already adopted for regulatory purposes for cogeneration. Indeed, the indicators presented extend the concept of primary energy saving to multi-generation systems, and create a set of further indicators to assess the environmental impact from such systems, covering a missing element in the current regulation. In addition, as also briefly discussed, starting from the energy performance assessment methodology formulated, environmental impact assessment models could be derived as well, leading to a unified framework defining the related indicators with the same formal structure.

Most of the material illustrated in this book has been elaborated starting from research works recently presented by the authors at scientific conferences and taught in doctoral courses and international seminars. The concepts and methods presented are intended to provide a base set of information, from which it is possible to start carrying out more detailed studies in various directions. For instance, these directions include the set up of advanced time-domain simulations and comparisons with actual system operation, economic evaluations based on multi-objective or multi-criteria optimisations, the incorporation of environmental analyses according to life-cycle assessment concepts, and so forth.

The DMG concepts and applications are also addressed in various papers written by the authors, listed in the references and recalled in the text. The material has been rearranged under an original and systematic structure, to reflect the authors' interdisciplinary view concerning the contents presented. This makes this book unique. Several other references to important and recent works appeared in international books and journals are provided to assist the interested reader in gathering the relevant information concerning the state of the art of the various topics addressed in this book. Our intention and hope is that the readers will find in our DMG energy models and analyses useful hints and benefits for their research and relevant activities.

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NOTATION

ACRONYM LIST

AB	Auxiliary Boiler
AC	Alternating Current
AGP	Additional Generation Plant
AHP	Absorption Heat Pump
ATHR	Absolute Trigeneration Heat Rate
CCGT	Combined Cycle Gas Turbine
CCHP	Combined Cooling Heat and Power
CERG	Compression Electric Refrigerator Group
CFC	Chlorofluorocarbons
CGP	Cooling Generation Plant
CHCP	Combined Heat Cooling and Power
CHG	Combustion Heat Generator
CHP	Combined Heat and Power
CHR	Cooling Heat Rate
CITHR	Cooling-side Incremental Trigeneration Heat Rate
COP	Coefficient Of Performance
DC	Direct Current
DCN	District Cooling Network
DER	Distributed Energy Resources
DFC	Direct-Fired Chiller
DFHP	Direct-Fired Heat Pump
DG	Distributed Generation
DH	District Heating
DMG	Distributed Multi-Generation
DSM	Demand Side Management
DR	Demand Response
DS	Distributed Storage
EDC	Engine-Driven Chiller
EDHP	Engine-Driven Heat Pump
EDS	Electricity Distribution System
EER	Energy Efficiency Ratio
EIHR	Electrical Incremental Heat Rate
EITHR	Electrical-side Incremental Trigeneration Heat Rate
EHP	Electric Heat Pump
EHR	Electrical Heat Rate
ESCO	Energy Service Company
EUF	Energy Utilisation Factor

FC	Fuel Cell
FESR	Fuel Energy Saving Ratio
GAHP	Gas-fired Absorption Heat Pump
GARG	Gas-fired Absorption Refrigerator Group
GAX	Generator Absorber heat eXchange
GDS	Gas Distribution System
GHG	Greenhouse Gas
GT	Gas Turbine
GWP	Global Warming Potential
HC	Hydro-Carbons
HCFC	Hydro-Chlorofluorocarbons
HDS	Hydrogen Distribution System
HHV	Higher Heating Value
HPR	Heat-to-Power Ratio
HR	Heat Rate
HRC	Heat Recovery Condenser
HRSG	Heat Recovery Steam Generator
HVAC	Heating Ventilation and Air Conditioning
ICE	Internal Combustion Engine
ICT	Information and Communication Technologies
IFAC	Indirect-Fired Absorption Chiller
IHR	Incremental Heat Rate
IPLV	Integral Part Load Value
ITHR	Incremental Trigeneration Heat Rate
LCA	Life Cycle Assessment
LHV	Lower Heating Value
MG	Multi-Generation
MPPT	Maximum Power Point Tracking
MT	Microturbine
mu	monetary units
ODP	Ozone Depletion Potential
OTHR	Overall Trigeneration Heat Rate
PCO2ER	Poly-generation CO_2 Emission Reduction
PCU	Power Conditioning Unit
PER	Primary Energy Rate
PES	Primary Energy Saving
PPES	Poly-generation Primary Energy Saving
pu	per unit (referred to a relevant base quantity)
PV	Photovoltaic
PV/T	Photovoltaic/Thermal
QI	Quality Index
RC	Rational Criterion
RES	Renewable Energy Sources
SE	Stirling Engine
SP	Separate Production
TD	Transmission and Distribution
TEUF	Trigeneration Energy Utilization Factor
THR	Thermal Heat Rate
TIHR	Thermal Incremental Heat Rate
TIT	Turbine Inlet Temperature

TITHR	Thermal-side Incremental Trigeneration Heat Rate
TPES	Trigeneration Primary Energy Saving
UHC	Unburned Hydro-Carbons
VPP	Virtual Power Plant
WAHP	Water Absorption Heat Pump
WARG	Water Absorption Refrigerator Group

SYMBOLS

B	hot water thermal energy [kWh_t]
C	cost, in [mu] or [mu/year]
$\mathbf{D}$	set of useful energy demand outputs
E	exergy [kWh]
F	fuel thermal energy [kWh_t]
G	solar irradiance [W/m^2]
H	hydrogen thermal energy [kWh_t]
L	losses [kWh]
Q	heat [kWh_t]
R	cooling [kWh_c]
S	steam thermal energy [kWh_t]
T	temperature [K]
W	electricity [kWh_e]
X	generic energy vector [kWh]
m	mass [g]
$\dot{m}$	mass flow rate [kg/s]
α	dispatch factor
β	capital charge factor
χ	electricity production cost [mu/kWh_e]
ε	effectiveness
η	efficiency
λ	cogeneration ratio
μ	emission factor [g/kWh]
ρ	price [mu] (related to specific quantity units)
ν	generic model parameter
Λ	lambda transform

SUBSCRIPTS AND SUPERSCRIPTS

Subscripts and superscripts are used to represent equipment, energy sources or end use, and to specify the measuring units. The above defined acronyms and uppercase Latin letters can be used as superscripts or subscripts as well. Numbers can also appear as subscripts to represent specific instances of the corresponding variables.

a	artificial
b	hot water
c	cooling

d	demand
e	electricity
f	fuel
h	hydrogen
i	input
o	output
p	poly-generation
rev	reversible
t	thermal
u	useful
vw	value-weighted
x	generic type of energy
y	cogeneration
z	trigeneration
A	ambient
C	Carnot cycle
I	investment
I	first law of thermodynamics
II	second law of thermodynamics
M	operation and maintenance
δ	dispersion
σ	stack

CONTENTS

LIST OF FIGURES